Introduced Enemies of the Giant African Snail, Achatina fulica Bowdich, in Hawaii (Pulmonata: Achatinidae)

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INTRODUCTION

The pestiferous giant African snail, *Achatina fulica* Bowdich, entered Hawaii in 1936 on two occasions, at least—by mail and in baggage from Japan. Unfortunately, this mollusk was undetected at the time and its breeding proceeded without interruption at a hatchery on Maui and, subsequently, on Oahu, until its discovery in 1938. By this time, sufficient numbers on both islands had escaped from their importers to establish widespread colonies.

For many years *A. fulica* infestations were limited to Oahu and Maui, but in 1958 they were found almost simultaneously on the islands of Kauai and Hawaii. Both infestations were controlled for a time but new outbreaks were discovered and control measures were reinstituted. In addition, African snails were found in Kalaupapa and Mauna Loa, Molokai, for the first time in September 1963, and there was an unconfirmed report from Lanai in November 1963.

INTRODUCTION OF PREDATORS

Various methods and chemicals were used in an attempt to eradicate the snails between 1938 and 1951 but it was apparent that these measures were no longer economically feasible and the introduction of natural enemies was explored. Dr. F. X. Williams, Associate Entomologist, Hawaiian Sugar Planters' Association Experiment Station, worked on this project in East Africa from December 1947 to June 1948 and indicated that carnivorous or rapacious snails (Streptaxidae) were probably the most effective enemies of *Achatina* observed in East Africa. Dr. J. C. Bequaert, eminent authority on the Achatinae in Africa, was also of this opinion.

As a result of these studies, enemies of the giant African snail were imported into Hawaii and held under quarantine conditions. These included the streptaxids, *Gonaxis kibweziensis* (E. A. Smith) and *Edentulina affinis* C. R. Boettger, the large carabid, *Tefflus zanzibaricus alluaudi* Sternberg, and a drilid species. Subsequently, additional predators were received from Exploratory Entomologist Noel Krauss and others. A list of the introductions made into Hawaii as possible *Achatina* predators is given in table 1.

Of the total introductions, the following predators, in order of importance, became established in Hawaii: 1, *Gonaxis quadrilateralis* (Preston); 2, *Euglandina*

rosea (Ferussac); 3, *Gonaxis kibweziensis* (E. A. Smith); 4, *Tefflus zanzibaricus alluaudi* Sternberg; 5, *Gulella wahlbergi* (Krauss).

Table 1. Organisms introduced into Hawaii for the control of the giant African snail.

Zonitidae			
Oxychilus cellarius (Muller)	New South Wales, Australia (European origin)	1950	V
Oleacinidae			
**Euglandina rosea* (Ferussac)	Florida	1955	*
Euglandina singleyana (Binney)	Goliad, Texas	1963	V
Oleacina oleacea straminea (Deshayes)	Cuba	1956	X
Oleacina sp.	Cuba	1956	X
Paryphantidae			
Rhytida inaequalis Pfeiffer	New Caledonia	1950	V
Paryphanta compacta Cox and Hedley	Near Forrest, Victoria, Australia	1950	V
Strangesta capillacea (Ferussac)	New South Wales, Australia	1950	V
Natalina caffra (Ferussac)	Durban, South Africa	1956	V
Streptaxidae			
Edentulina affinis C. R. Boettger	Diani Beach, Kenya	1957	X
**Gonaxis kibweziensis* (E. A. Smith)	Diani Beach, Kenya	1952	*
**Gonaxis quadrilateralis* (Preston)	Kwale, Kenya	1957	*
Gonaxis vulcani Thiele	Congo Republic (Belgian Congo)	1956	X
Streptaxis contusis (Ferussac)	Rio de Janeiro, Brazil	1961	X
Gulella bicolor (Hutton)	Manila, P.I., Kuala Lumpur, Malaya, Saipan, Mariana Islands	1957	X
**Gulella wahlbergi* (Krauss)	Durban, South Africa	1956	*
Gulella sp.	Congo Republic (Belgian Congo)	1956	X
Ptychotrema walikalense Pilsbry	Congo Republic (Belgian Congo)	1956	V
Ptychotrema sp.	Congo Republic (Belgian Congo)	1956	V
Carabidae			
Damaster blaptoides blaptoides Kollar	Fukuoka, Japan	1958	X
Damaster blaptoides rugipennis Motchulsky	Yamabe, Hokkaido, Japan	1958	X
Scaphinotus striatopunctatus (Chaudoir)	San Francisco Bay area, California	1956	X
Scaphinotus ventricosus (Dejean)	San Francisco Bay area, California	1956	X
**Tefflus zanzibaricus alluaudi* Sternberg	Diani Beach, Kenya	1952	*
Tefflus purpureipennis wituensis Kolbe	Diani Beach, Kenya	1959	X
Tefflus tenuicollis (Fairmaire)	Congo Republic (Belgian Congo)	1956	X
Tefflus jamesoni Bates	Congo Republic (Belgian Congo)	1956	X
Thermophilum hexastictum Gerstaecker	Diani Beach, Kenya	1957	X
Lampyridae			
Lamphrophorus tenebrosus (Walker)	Peradeniya area, Ceylon	1954	X
Drilidae			
Species ?	Kenya, East Africa	1948	V

V Quarantine only
X Released
* Recovered

1. *Gonaxis quadrilateralis* (Preston).

The streptaxid, *G. quadrilateralis*, introduced from Kwale, Kenya, East Africa in 1957 is without question the most outstanding introduced enemy of *Achatina* in Hawaii (Davis, 1961). It has become well established in almost all of the original 25 release points and despite the removal of over 12,000 from various release points for colonization in other snail-infested areas and despite minor environmental reductions by rats and attacks of the endemic terrestrial flatworm, *Geoplana septemlineata* Hyman, most of the original release points remain well-populated with all ages of *Gonaxis*. Moreover, *Gonaxis* has greatly increased its range and numbers. For instance, at Tantalus Drive, Oahu it now occupies 50 or more acres. In this same locality, thousands were washed down the *Bryophyllum*-covered slopes during a heavy rainstorm in 1960. This will tend to update Mead (1961, p. 134) who stated that "Two years after its release, it was still holding a weak second place, and, in general, the slow uncertain developments were disappointing." (See figure 1.)

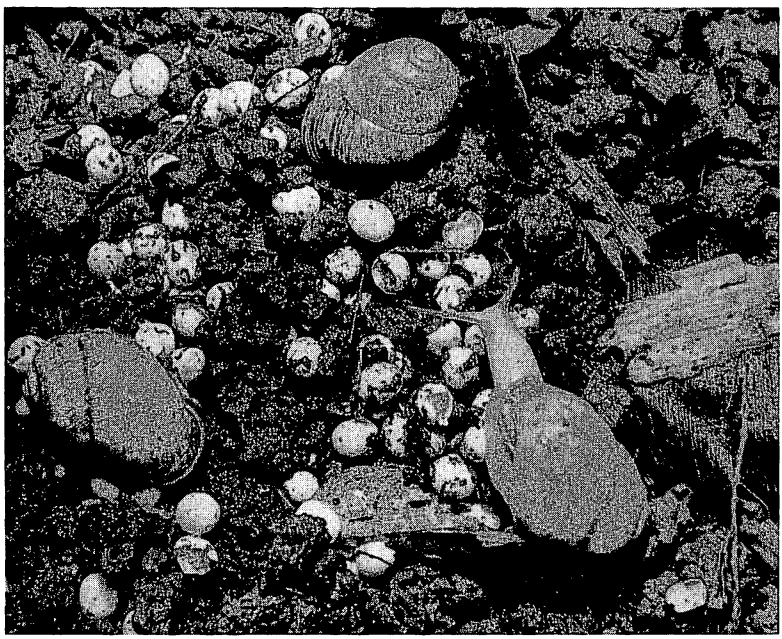

FIGURE 1. *Gonaxis quadrilateralis*, the most effective egg and juvenile predator of the African snail, in position to rasp the egg shell prior to feeding on the embryonic snail.

Observations made at most of the 25 original release points indicate that it takes three years for strong colonies to develop. *Gonaxis* can then be removed for redistribution without jeopardizing the remaining population. The release points are still under continued close surveillance.

Under field conditions, *G. quadrilateralis* does not appear to be as cannibalistic

as *G. kibweziensis* and this may explain the persistence of strong colonies at or near the original release points years after release. Both *Gonaxis* species are very devastating to the egg clutches of *Achatina* and are almost constantly found feeding on juvenile African snails up to 35 mm. in length. Their other prey include *Subulina octona*, *Bradybaena similaris*, several species of native terrestrial snails, and *Euglandina rosea*. Interaction between *G. kibweziensis* and *G. quadrilateralis* has never been observed in the field despite the overlapping of some populations, but undoubtedly occurs, however.

Noteworthy were two observations in 1960 of *G. quadrilateralis* attacking *Achatina* which measured 3 and 4 inches in length respectively. The first observation on the 4-inch specimen occurred at Kahana Bay, Oahu and lasted 3.5 hours. Feeding was partial but apparently sufficient to cause the death of the snail. The second observation took place at Lanikai but, after an hour, both *Gonaxis* and *Achatina* moved on (Davis 1961).

G. quadrilateralis and *G. kibweziensis* are similar in appearance but the former is almost twice as large, has a wider aperture and bright orange antennae; the antennae of the latter are dark. The habits and habitats of both species are similar; however, *G. kibweziensis* tends to get considerably farther from the release point in a comparable period. Embryonic *Gonaxis* are enclosed in a pod of earthen accretion, possibly cemented together by some secretion of the female. The "pods" are usually laid in porous soil and the laying season appears to begin in October in some localities.

In January 1961, an *Achatina* infestation was found at Hana, Maui for the first time. When first observed, eggs, infants, and juveniles were very abundant and no empty *Achatina* shells were observed. *Gonaxis quadrilateralis* was introduced on Jan. 12, 1961 and periodic observations indicate that this carnivorous snail is taking a heavy toll of egg, infant and juvenile *Achatina*.

Noticeable reductions in snail populations were first observed three years ago on Tantalus Drive, the Old Pali Highway on Windward Oahu, and at the State Hospital, Kaneohe. Since that time *G. quadrilateralis* has been steadily increasing at most of the release points in the state.

2. *Euglandina rosea* (Ferussac).

The carnivorous snail, *Euglandina rosea* was introduced from Leesburg, Florida in 1955 for trial on *A. fulica*. In Florida it feeds on the citrus tree snail, *Drymaeus dormani* (Binney), and is also known to feed on *Liguus* and other species of land snails. (See figure 2.)

In Hawaii, mature *E. rosea* shells average 50 mm. in length and 20 mm. in width and are usually pink to tan in color. They are elongate and grooved more or less longitudinally. The eggs are large, 4.25 × 3 to 3.25 mm., white in color and are usually laid in clutches of 25 to 30 at the bases of trees, in forest litter, and on grassy roadside shoulders.

Under quarantine insectary conditions, mature *E. rosea* fed on *Achatina* up to 40 mm. but preferred juveniles between 15–30 mm. Upon release from quarantine, initial releases were made as follows: 365 at Hauula, Oahu between November and December of 1955; 156 at the Kailua–Waimanalo Junction between Novem-

ber and March of 1955–1956, respectively, and 95 in the Makiki District, Honolulu in March, 1956.

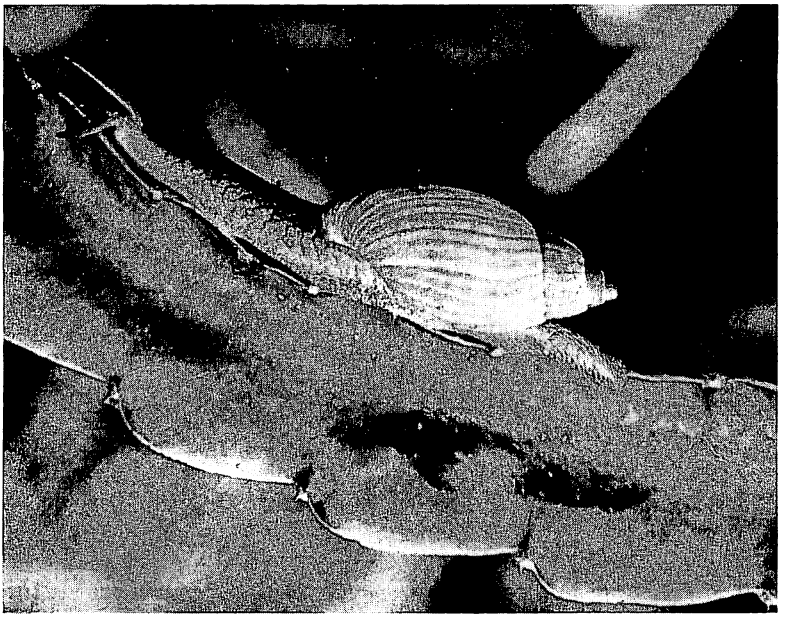

FIGURE 2. *Euglandina rosea*, introduced from Florida in 1955 and well established on Oahu, Hawaii, and Maui.

By 1957 over 2,483 *Euglandina* were recovered from Hauula and Makiki, Oahu and, by December, 1958, over 12,000 had been collected from these localities and distributed to other African snail infestations in the State.

Field observations indicated that *E. rosea* was strongly attracted to the garden snail, *Bradybaena similaris* (Ferussac) and this was supported by orchid growers on the neighboring islands of Kauai and Hawaii who reported drastic reductions in *Bradybaena* populations which they attributed to *E. rosea*.

Inconclusive feeding tests conducted with *Euglandina* and *Bradybaena* between May and June 1958 indicated a range of two to six *Bradybaena* consumed each day by 10 *E. rosea* over a period of 32 days.

Between 1959 and 1962, *Euglandina* populations were at a very low level. Interaction with *Gonaxis quadrilateralis* was frequently observed and documented, particularly at Kahana Bay, Waikane, Makiki, and Tantalus Drive, Oahu. In all instances, the aggressive *G. quadrilateralis* was victorious. The endemic, terrestrial, triclad turbellarian flatworm, *Geoplana septemlineata* Hyman was reported by Mead (1963) as preying upon the African snail on Oahu, killing even the largest specimens. He also reported that *G. septemlineata* was observed killing the predatory snails *Euglandina rosea*, *Gonaxis quadrilateralis* and the slug *Deroceras laeve*. However, field observations of the flatworm appear to be very limited

and, considering the ubiquity of both *A. fulica* and *Euglandina*, the distribution of *G. quadrilateralis*, and the upsurge of *Euglandina* populations during the latter part of 1963, it is unlikely that the carnivorous streptaxid, *G. quadrilateralis* and the flatworm *G. septemlineata* contributed appreciably to the 1959–1962 ebb of *E. rosea*. Roadside herbicide sprays during this period however, took a heavy toll of *E. rosea* in the Makiki–Tantalus perimeter.

In addition to Oahu, *Euglandina* is well established on Kauai, Maui, and Hawaii and survived the chemical eradication programs directed against *Achatina* on Kauai and Hawaii. It is steadily building up and spreading on these islands.

3. *Gonaxis kibweziensis* (E. A. Smith).

G. kibweziensis was among the first of the carnivorous snails to be introduced into Hawaii for the biological control of *A. fulica*. Its predaceous behavior was well documented both prior to, and after liberation by Abbott (1951), Williams (1951, 1953), Kondo (1952, 1956), Weber (1954), Davis (1954, 1958, 1960, 1961), Pemberton (1954, 1956), Krauss (1955), and Peterson (1954, 1957).

G. kibweziensis reaches a maximum length of 22 mm. and has an orange or yellowish "foot" and a pair of antennae which darken during projection. The shell is whitish, conspicuously grooved and is described by Williams (1951) as wide and dorsoventrally distorted, as if stepped upon obliquely, so that the aperture is far off center. The orange mollusk is often visible through the shell.

The first liberation of this species was made at Kaneohe, Oahu on June 3, 1952, followed by liberations at other localities on Oahu and Maui in 1954, 1955 and 1957.

Like the closely related species, *G. quadrilateralis*, *G. kibweziensis* is strongly attracted to the egg clutches of *Achatina* and as many as 12 adults have been collected from a single clutch (200 to 400 eggs) on Maui. Over half of the 5,000 *Gonaxis* shipped to Hawaii from Agiguan, Mariana Is. in 1955 were collected from egg clutches. *Gonaxis* is very secretive and, when not in the *Achatina* egg clutches, can be found under forest litter, at the edge of forests, and in grassy areas. It tends to move into open country, as observed on Agiguan and at Kaneohe, Oahu. Banana groves are ideal habitats for *Gonaxis*, especially the debris at the base of the clones, where, even during dry spells, sufficient moisture persists to enable *Gonaxis* to remain active and prey incessantly on *Achatina* eggs, infants and juveniles. Actual predation was observed hundreds of times during daylight hours under these conditions, however, foraging was usually at night or during rainy days.

Except for a very outstanding colony at Haiku, Maui and the State Hospital, Kaneohe, Oahu where it has spread over nearly one square mile, *G. kibweziensis* has not flourished at most release points and its performance to date under Hawaiian conditions has been disappointing (Davis 1958). It has not departed from its habits or behavior since its introduction in 1952.

4. *Tefflus zanzibaricus alluaudi* Sternberg.

The predaceous carabid, *T. zanzibaricus alluaudi*, was found by Williams (1951) to feed on *Achatina* in Mombasa, East Africa. He sent specimens to Hawaii for study and additional shipments were made by Krauss in 1951–52. Krauss (1955) subsequently reported the identity of this species. Studies of the biology of this species under Hawaiian quarantine conditions were made by Weber (1954) and

the first release of marked specimens was made in Kaneohe, Oahu on June 3, 1952. This was followed by releases in 1954, 1957, and 1958.

Single specimens of *Tefflus* were recovered at Kaneohe in 1954 and 1959 and two were recovered in the same locality in 1963, indicating borderline establishment.

T. zanzibaricus alluaudi is a large black carabid species, a little under two inches long and is predacious in both larval and adult stages. The adults are very secretive and no appraisal of its worth under field conditions has been possible up to this time.

5. *Gulella wahlbergi* (Krauss).

The carnivorous snail was introduced from South Africa in 1956 and 1957 and recovered in Nuuanu Valley, Honolulu on September 8, 1960. No additional recoveries have been made up to the present time, and therefore its worth as a predator cannot be ascertained. Because of its small size (about the size of grain of corn) it is unlikely that it will be of any importance.

OBSERVATIONS OF PREDATORS IN HAWAII

There are complex biotic and physical factors that interact to govern giant African snail populations. Many of these are discussed in detail by Mead (1961) in his excellent book on the snail. The present authors recognize that there are many factors involved, but detailed observations of snail predators made since the preparation of Mead's book strongly indicate that *Euglandina rosea* and *Gonaxis quadrilateralis* are exerting an important depressing effect upon *Achatina* egg, infant, and juvenile populations in Hawaii.

The senior author has closely watched the various areas in Hawaii infested with giant African snails for the past 9 years and has assisted and directed release of many of the introduced predators. The junior author made observations on the movement and diurnal activity, and measured shell sizes of various snail populations in 1958, 1959 and 1961. Individual snails were measured with calipers to the nearest sixteenth of an inch and in the following report sizes will often be referred to as the average size and a standard deviation given in sixteenths of an inch. Over 7,200 snails were collected and measured during this study. Continued observations of the snail populations were made under the direction of the senior author through December, 1963 to ascertain whether the *Achatina* juvenile and infant populations reappeared.

Population Studies

Kaneohe, Oahu site.

One observation site was at Kaneohe (Mahinui), Oahu in a heavily wooded area bordering a stream. This area had an old infestation of very large snails. A sample of 100 snails on September 15, 1958 measured 3 ± ½ inches (table 2). Another sample of 385 snails measured on September 23 had the same average size. Many of the large snails climbed the trunks of the trees in the early morning and remained there until evening when they became active and wandered about on the forest floor searching for food. Sample areas on the trunks of some of the trees in the daytime had as many as 60 snails each. Some large snails remained

Table 2. Size of Achatina at Kaneohe, Oahu

Date	On trees and ground	On vegetation	On and in ground
IX-15-1958.....	3″ ± ½″	—	—
IX-23-1958.....	3″	2″ ± 6/16″	7/16″ ± 3/16″
IX-16-1961.....	3½″ ± 5/16″	none	Only egg clutches

on the ground and secreted themselves beneath debris. Beneath the trees a number of plants such as ti, *Cordyline terminalis*, grew to a height of 2 to 4 feet. There was a smaller-sized group of snails that rested upon the stems and undersides of the leaves of these plants during the daytime. A sample of 129 of these snails was collected on September 23, 1959 that measured 2 ± 6/16 inches. On the ground there was still another group of very small snails. In a relatively few minutes, 163 such snails were collected with a hand rake and their average measurement was 7/16 ± 3/16 inches. Thus, the daytime giant African snail population consisted of very large snails resting on the trunks of trees or on the ground, smaller-sized snails resting on the low plants, and juvenile snails on or buried in the ground.

One of the first releases of *Gonaxis kibweziensis* was approximately 100 yards from this observation area. However, a swift-flowing irrigation ditch effectively barred the *Gonaxis* from entering the area.

An area 10′ × 10′ was enclosed with a hardware cloth fence approximately 1′ high in which numbered giant African snails were placed during September 1958 for later study by Dr. A. R. Mead. The top of the wire was bent inward to prevent the snails from climbing out, however, a number of additional giant African snails climbed into the enclosure during the last part of 1958 and the first half of 1959. *Euglandina* were occasionally also found trapped within the enclosure.

On September 16, 1961, three years after the earlier detailed observations were made, the area was revisited. The most noticeable change was that there were no longer groups of large snails clustered on the trunks of the trees, and one had to look at a number of trunks to find any snails. The lack of snails was not due to aestivation because no aestivating snails could be found, as rain had been falling in the area. A sample of 250 snails was measured and found to be 3½ ± 5/16 inches, or approximately one-half inch larger than in 1959. Snails numbered in 1958 were found both inside and outside the wire enclosure indicating that some of the same snails measured earlier were still present. A search among the plants where numerous 2-inch snails could be found previously, uncovered no 2-inch snails and only a single 3-inch individual. There was no evidence of the presence of small snails in this habitat although the plants appeared to be just the same as before. Digging in the ground above the flood level in the exact area where before many juvenile snails could be found revealed not a single juvenile snail. Seven clutches of *Achatina* eggs were uncovered, in some of which small living snails were present. In a sample of dead

Achatina shells measured in 1958, 69 percent of the sample was under 2 inches in length, while only 29 percent of the 1961 dead snails were of this size. Within the 10-foot fenced area there was a total of 50 *Euglandina* shells, indicating that there had been a considerable amount of activity of this predator in the area.

The conclusions drawn from these observations were that in the Kaneohe area the adult *Achatina* population was getting older and larger in its average size, owing to the lack of replacement by younger snails. Eggs were still being laid but before the juvenile snails could attain adult size they were being fed upon by *Euglandina*. The presence of empty shells indicated that virtually all of the juvenile snails were killed before they attained a length of 1½ inches.

Mt. Tantalus, Oahu site.

Other detailed observations were made in an area on Mt. Tantalus which lies as a backdrop to Honolulu. On September 5, 1958, under a dense thicket of haole koa, *Leucaena glauca*, a 20-foot circular area was selected to determine the movement of *Achatina* and 1,000 snails in it were marked with a band of white enamel.

In an adjacent area a sample of "the smallest *Achatina* that could be found" was raked from the ground on September 15, 1958. The mean size of the 37 snails selected in this category was $1\frac{10}{16} \pm \frac{3}{16}$ inches. A sample of 100 of the larger snails, $2\frac{1}{16} \pm \frac{6}{16}$ inches, was collected from the ground and trunks of the haole koa trees on September 13. Another sample of 200 snails collected on October 17 measured $1\frac{15}{16} \pm \frac{1}{4}$ inches.

Euglandina were very abundant and active throughout this area and on rainy mornings many could be collected on the road. *Gonaxis quadrilateralis* could be found by raking but was rather scarce. *Gonaxis* was observed attacking *Euglandina* eggs on several occasions. *Euglandina* became less abundant in the area but *Gonaxis* populations increased rapidly.

Three years later, on September 15, 1961, the 20-foot circular area in which 1,000 snails had been painted was examined again. Only a few snails were resting on the haole koa tree trunks. A hand rake was used to dig over the entire area but only 168 *Achatina* were found where there had previously been 1,000. Not a single individual was aestivating. In addition, 48 *Gonaxis* were collected within the same area where none had been observed before. Numerous empty *Achatina* shells were encountered. A number were discarded at first, but later all those found were saved, measured, and found to average $2\frac{5}{16} \pm \frac{5}{8}$ inches. Only a single shell was found that was one-half inch long, 17 percent were between 2 and 3 inches in length and 85 percent were between 3 and 4 inches in length. A sample of snails was collected from the trees and the ground at this (mile 0) and several near-by locations and their size measured. The average size of the snails at different dates is included in table 3. The adult population of snails in these locations increased in size by approximately one-half inch during the three years.

In looking for the "smallest *Achatina* that could be found" in the same area where three years previous 1¼- to 1½-inch snails were abundant, the smallest snail found in 1961 was 1⅞ inches in length. Where the ground had been littered with many dead shells of this and the smaller size ranges, in 1961 there were very

Table 3. Size of Achatina on Mt. Tantalus, Oahu

Location	X-17-1958	VI-2-1959	IX-15-1961
Mile 0 (670').....	1 15/16" ± 1/4"	2 5/16" ± 1/4"	2 1/16" ± 5/16"
Mile 0.2.....	2 1/4" ± 5/16"	—	2 1/16 ± 5/16"
Mile 0.4.....	2 1/2" ± 1/4"	2 1/16" ± 1/4"	—
Mile 0.8.....	—	2 1/16" ± 1/2"	2 13/16" ± 1/16"
Mile 1.2.....	—	—	3 5/16" ± 9/16"

few small empty shells. No *Achatina* egg clutches were uncovered but numerous *Gonaxis* were dug from beneath the surface of the ground. The only *Euglandina* seen was found several hundred yards away and was observed attacking an *Achatina* that was approximately 2½ inches long.

In the Mt. Tantalus area the first pronounced predation of *Achatina* was by *Euglandina* which developed extremely large populations (over 10,000 snails were collected from 1957 to 1962). When the most favorable-sized juvenile *Achatina* and the *Bradybaena* had been consumed, with perhaps, some predation by *Gonaxis*, the *Euglandina* population became extremely reduced. *Gonaxis* populations increased tremendously from 1959 to 1961 and attacked the eggs and infant *Achatina*, as well as the eggs of *Euglandia*. Thus in September 1961, there was no sign of infant or juvenile *Achatina*, almost no empty juvenile shells were found, and the adult population was reduced by approximately 80 percent. The average size of the *Achatina* shells had increased by approximately one-half inch.

Absence of small snails in populations with predators.

Achatina shells were measured in several localities in 1958, 1959, and 1961. These collections included juvenile snails taked from the ground as well as larger snails removed from vegetation and trees. The number of individuals of different sizes is given in table 4. The four populations sampled in 1958 and 1959 were believed to be of normal sizes, that is, before the build-up of predaceous snails. The majority of the snails were less than 2.5 inches in length. In 1961 almost no snails were found smaller than 2.5 inches in the two populations sampled. As discussed above, this reduction in the number of small snails was believed to be due mainly to the activity of *Gonaxis* on Mt. Tantalus and of *Euglandina* at Kaneohe.

Observations of January 1964.

Detailed studies at Mahinui, Kaneohe and on Mt. Tantalus, discussed above, indicate that there had been a striking reduction of *Achatina* populations from 1958 to 1961 attributed to the carnivorous snails, *Euglandina rosea* at Mahinui and *Gonaxis quadrilateralis* on Tantalus. *Achatina* eggs and juveniles were exceedingly scarce between 1961 and 1964.

Observations made at these localities in January 1964 disclosed that the giant

African snail populations were considerably below the 1961 level and that there was a dearth of *Achatina* eggs and an absence of juveniles.

Table 4. Number of snails of various sizes in Hawaiian Achatina populations in inches.

Location	0.5″	1″	1.5″	2″	2.5″	3″	3.5″	4″	4.5″	5″
Hauula, Oahu* November 1958.....	1043	893	68	25	16	13	3	0	0	0
Kaneohe, Oahu† October 1958.....	197	52	10	41	73	36	15	0	0	0
Paia, Maui May 1959.....	0	77	118	109	148	40	9	0	0	0
Waialua, Oahu November 1958.....	7	24	12	17	100	19	0	0	0	0
Mt. Tantalus, Oahu September 1961.....	0	0	0	4	60	120	15	1	0	0
Kaneohe, Oahu September 1961.....	In egg clutches	0	0	0	8	29	95	99	18	1

* Isolated from predator release sites.
† Isolated from Kaneohe area discussed in paper.

Euglandina were active at Mahinui and appeared to be surviving on slugs, *Bradybaena similaris*, and transient African snails that occasionally entered the study area. On the other hand, *Euglandina* had practically disappeared from the Tantalus study area and had been replaced by strong colonies of *Gonaxis quadrilateralis* of all ages. These appeared to be subsisting on *Subulina octona* and terrestrial native snails in the absence of *Achatina* eggs and juveniles. Weather conditions were ideal for snail activity at the time observations were made.

At Moanalua, through an oversight, neither of the predaceous streptaxids, *Gonaxis kibweziensis* or *G. quadrilateralis*, was ever released. When visited on January 22, 1964, numerous giant African snail egg clutches and juveniles up to 35 mm. long were observed in the jungle thicket of *Leucaena glauca*. A few empty *Achatina* shells were seen but worthy of note was the abundance of the slug *Veronicella leydigi* Simroth, and the snails, *Subulina octona* (Brug.) and *Prosopeas javanicum* (Reeve). No signs of *Euglandina rosea* or the predaceous flatworm, *Geoplana septemlineata* were seen. This was an old giant African snail infestation and, judging from the abundant replacement populations, was in sharp contrast to infestations dominated by predators.

In summarizing the observations at Mahinui and Tantalus, it is obvious that *Achatina* populations are at an all-time low at both localities and are typical of many areas dominated by *Gonaxis* and other predators. On the other hand, old infestations, such as at Moanalua which have not been exposed to *Gonaxis*, show

a preponderance of *Achatina* replacement populations as well as other terrestrial snails and slugs.

SUMMARY

A. fulica was discovered in Hawaii in 1938, following its illegal introduction to the islands of Maui and Oahu in 1936. Eradication and control measures with chemicals were attempted but were unsuccessful. In 1958, infestations were found almost simultaneously on Kauai and Hawaii and, although successfully eradicated, appeared on these islands in new localities. Subsequently, infestations were found in two localities on the island of Molokai in September, 1963.

Biological control measures were sought for the control of *A. fulica* and, after the introduction of many predators from various parts of the world, the following, in order of importance, became established: (1) *Gonaxis quadrilateralis*, (2) *Euglandina rosea*, (3) *Gonaxis kibweziensis*, (4) *Tefflus zanzibaricus alluaudi*, and (5) *Gulella wahlbergi*.

Continuous observations at the original release points over eight years indicated devastating effects on *Achatina* egg clutches by *G. quadrilateralis* and *G. kibweziensis*, and incessant predation of juveniles by these streptaxids and the oleacinid, *Euglandina rosea*. In addition, *E. rosea* appeared to be an avid predator of the pestiferous garden snail, *Bradybaena similaris*.

In 1960 significant population reductions of *Achatina* were noted in several widely separated localities on Oahu, particularly on Tantalus Drive and Mahinui, Kaneohe. Snail measurements, made in 1958, 1959 and 1961, showed little or no replacement populations and indicated that the snails were getting older and larger in size and that the carnivorous snail *Euglandina* was very active at Mahinui and exerting considerable pressure on the juvenile *Achatina*. At Tantalus however, the aggressive *Gonaxis quadrilateralis* had replaced *E. rosea* as the dominant predator, had increased its numbers tremendously, and was attacking the giant African snail eggs and infants, as well as the eggs of *Euglandina*. The adult *Achatina* population was reduced by approximately 80 percent and the average size of adult *Achatina* shells had increased by one-half inch.

Observations in January 1964 indicated a spectacular population reduction at Mahinui with only a few adult *Achatina* and *Euglandina* remaining. No *Achatina* eggs, infants or juveniles were found, nor was there any evidence of there having been any replacements between 1961 and 1964. At Tantalus Drive only adult *Achatina* averaging 3 inches in length were found; *Euglandina* had virtually disappeared and *Gonaxis quadrilateralis* had spread over an area of 50 acres with abundant replacement populations compared to little evidence of *Achatina* eggs or juveniles. Also included in these observations was an old giant African snail infestation at Moanalua which contained great numbers of *Achatina* egg clutches, infants, juveniles and adults. Also, *Subulina octona* (Brug.), *Prosopeas javanicum* (Reeve), and a slug, *Veronicella leydigi* Simroth, were fairly common. Through an oversight, neither species of *Gonaxis* had been released in this area. *Euglandina* and *Geoplana septemlineata* were not observed. This was in sharp contrast to giant African snail populations dominated by predators.

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